# A Versatile High Pressure Test Bench for Supercritical Fluid Research

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Research involving critical fluids is a sub-discipline of high pressure technology, and should also encompass the evaluation of components (pressure gauges, flowmeters, pumps, etc.) that are routinely used in measuring experimental data and mechanically conducting extractions or reactions. A unique system has been developed at NCAUR for performing these tasks, which can include the calibration of various types of pressure gauges, determining the leak status of high pressure valves, or testing the efficacy of repaired pumps or compressors used for fluid delivery. The pressure test bench is capable of generating reproducible pressures to 20,000 psi, and features both low and high calibration gauges which are routinely used in the NCAUR High Pressure Laboratory. The bench is capable of both producing and/or receiving pressure signals, allowing it to be used for many types of pressure calibration and testing for fluid leakage. A description of the design, construction, and use of this pressure test bench will be presented, including provision for automatic data recording of pressure, flow, and other variables which impact on using critical fluids in a high pressure laboratory.

#### Introduction

Various high pressure components, such as pressure gauges, transducers, relief valves, shut-off valves, micrometering valves, and gas booster pumps, are used at the High Pressure Laboratory of NCAUR to construct small scale pilot plant apparatus. References pertaining to the control systems and a variety of apparatus constructed at the High Pressure Laboratory can be found in previously published literature. The High Pressure Laboratory is well stocked with new as well as used components. The unknown condition of the many used components and the desire to check the performance of repaired pumps precipitated the need for a pressure test bench. It should be noted that it was not our intent to design or construct a test bench to proof test or burst test pressure vessels. Photographs of the completed test bench, front and back, are shown in Figures 1 and 2.

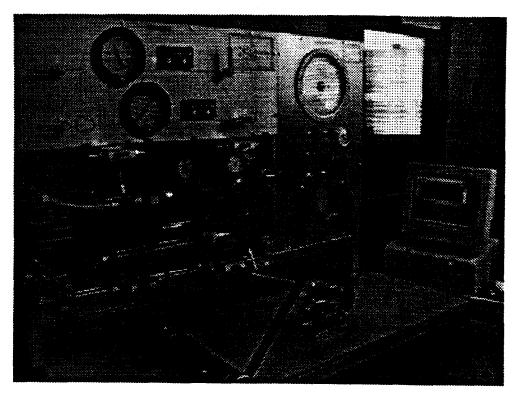


Figure 1. Photograph of front view of pressure test bench.

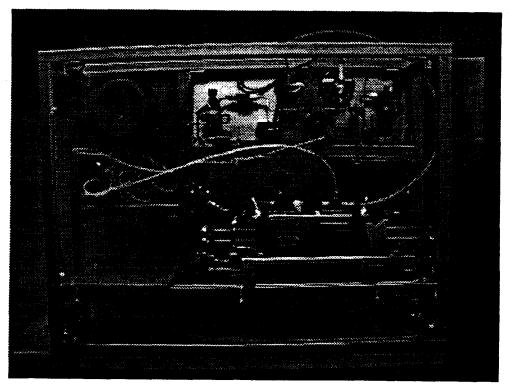


Figure 2. Photograph of back view of pressure test bench.

# Design

The design for the pressure test bench was finalized after giving consideration to safety, functionality, and available existing components. A schematic of the test bench is shown in Figure 3.

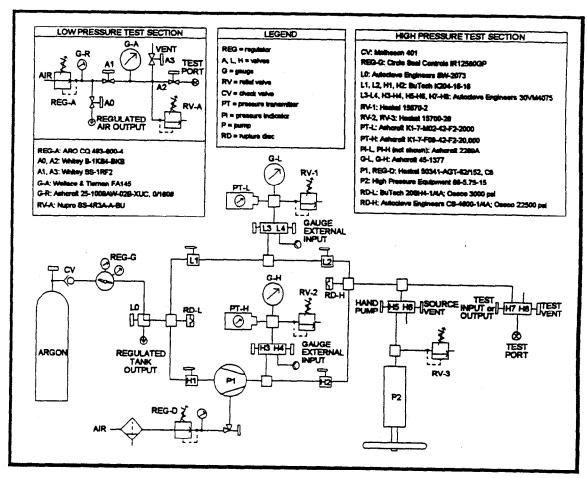


Figure 3. Schematic of the pressure test bench.

The test bench was divided into two sections: one for low pressure testing (using compressed air) and one for high pressure testing (using a cylinder tank of argon). The low pressure test section provides controlled compressed air up to 150 psi, supplied by the High Pressure Laboratory's dedicated air compressor (2T25A-240; Emglo, Johnstown, PA). The high pressure test section has the capability to provide cylinder tank pressure through a precision regulator up to 2000 psi. Higher pressures up to 20,000 psi are obtained through the use of an air-driven gas booster pump. Precision adjustments of

pressures up to 15,000 psi are allowed on the high pressure test section through the use of a hand pump pressure generator. In consideration of safety and to protect components of the test bench, relief valves and rupture discs were included in the design. An electrical signals connection panel was also included to allow for data acquisition of the pressure signals and calibration of the high pressure test section's digital pressure indicators. The performance of various components, such as those that accept pressure and those that generate pressure, can be checked at the test bench. Design is such that leak checking of components at pressures up to 15,000 psi can be accomplished by observance of a pressure drop (bleed rate).

#### Construction

Certain components were chosen for inclusion in the test bench, such as the gas booster pump and the hand pump pressure generator, to duplicate components already used in the High Pressure Laboratory. Many of the remaining components were selected based on the High Pressure Laboratory's stock of existing parts. If purchased new, the total cost for components and parts used in the construction of this test bench would be approximately \$15,800. Tables 1 and 2 provide information on all of the components incorporated in the test bench.

Table 1. Pressure test bench components.

ITEM GRAWING REFERENCES	124407-814-8-14-8-				
air regulator (REG-A)	MANUFACTURER ARO	PART NUMBER	PARCE	QTY.	TOTAL
needle valve (A0, A2)	Whitey	CQ493-800-4 B-1KS4-BKB	\$34.50	1	\$34.56
needle valve (A1, A3)	Whitey	SS-1RF2	30.80	<del></del>	61.20
pressure gauge (G-A)	Wallace & Tiernen	FA145 (62A-2A-0100)	1525.00		92.80 1525.00
pressure gauge (G-R) relief valve (RV-A)	Asharot	25-1008AW-028-XUC, 0/160#	55.70		55.70
1/4-Inch tube to 1/4-Inch NPT male albow	Nupre	88-4R3A-A-BU	124.15	1	124.15
1/4-inch tube to 1/4-inch NPT female alborr	Swagelok Swagelok	8-400-2-4 8-400-8-4	3.60	3	10.80
1/4-inch tube union tee	Swapelot	B-400-3	4.80 5.70	1	4.60
1/4-inch tube builthead union	Swegelck	B-400-61	3.50	3	22.80
1/4-inch tube to 1/8-inch NPT male connector	8wagalak	88-400-1-2	4.70	1	18.80
1/2-inch NPT to 1/4-inch NPT bushing 1/4-inch pleatic tubing (per foot)			0.95	2	1.90
gas cylinder support clamp	Weatherhead Fisher Scientific	PT-240-04 10-565	0.10	14	1.40
argon, 220 cubic feet industrial grade	BOC Gases	10-365	29.54	1	29.54
check valve (CV)	Matheson	401V	18.48	1	18.46
tank regulator [REG-G]	Circle Seel	R12580GP	528.00	1	93.00 528.00
2-way straight valve [L0]	Autociava Engineers	SW-2073	105.00	1	105.00
bell valve (L1, L2, H1, H2) 3-way/2-atem manifold valve (L3-L4, H3-H4, H5-H6, H7-H6)	Bu Tech	K204-16-18	180.00	4	720.00
relief valve (RV-1)	Autociave Engineers Haskel	30VM4075	140.00	4	560.00
relief valve (RV-2, RV-3)	Heate	15676-2 15700-26	195.00	1	195.00
pressure transmitter [PT-L]	Ashcroit	K1-7-M02-42-F2-2000	581.00 213.50	2	1122.00
pressure transmitter (PT-H)	Asherot	K1-7-F00-42-F2-20,000	253.80		213.30 253.80
digital panel meter (PI-L, PI-H)	Ashcrat	2289A	260.25	2	560.50
pressure gauge [G-L] pressure gauge [G-H]	Ashcrott	45-137788-02B, 0/2000#	205.70	<del></del> -	205.70
gas booster pump [P1, REG-D]	Ashcrott Heatel	45-137788-098, 0/20,000#	363.10	1	363.10
pressure generator [P2]	High Pressure Equipment	50341-AGT-62/152, C8	5123.00	1	5123.00
safety head [RD-L]	Bu Tech	88-5.75-15  208H4-1/4A	1950.00	. 1	1950.00
rupture diek (RD-L)	Oseco	8-1843-01	71.00 21.80		71.00
safety heed [RD-H]	Autociave Engineers	C8-4800-1/4A	66.00		21.80
rupture disk [RD-H] 1/6-inch tube to 1/4-inch NPT male connector	Oseco	R-6664-01	32.30	<del>- i -</del>	32,36
1/8-inch tube bulkheed union	Swagelok	88-200-1-4	5.80	2	11.90
1/4-inch MP tee	Swagelek Autodaye Engineers	88-200-61	15.60	1	15.80
1/4-inch MP cross	Autociave Engineers	CTX4440 CXX4444	42.00	2	84.00
1/4-inch HP tee	Autociene Engineers	C74440	48.00 32.00	1	48.00
1/4-inch HP pross	Autosiana Engineers	CX4444	58.00	4 2	208.00
1/4-inch HP plug	Autocione Engineers	AP40	4.70	<del></del>	116.00
MF adapter 1/4-inch NPT to 1/4-inch HP MF adapter 1/8-inch LP to 1/4-inch HP	Autociave Engineers	BMAANS	23.50	<del>-i-</del>	23,50
IMF adapter 1/4-inch NPT to 1/4-inch MP	Autociene Engineers	8M24C3	23.00	2	46.00
1/4-inch NPT cross	Autocieve Engineers Cajon	6M44M6	23.50	2	47.00
1/4-inch NPT plug	Capan	88-4-C8	29.40	1	29.40
1/4 least 140 bets (out 5 - 1)		3			9.00
1/4-inch MP tube (per foot)	Autociena Engineers	M815-002	1.53	2	3.06
1/4-inch HP tube (per foot)	Autociave Engineers Autociave Engineers	MS15-082 MS15-081	8.50	7.3	\$2.05
1/4-inch HP tube (per foot) 1/6-inch SS tubing					\$2.05 303.30
1/4-inch HP tube (per foot) 1/6-inch SS tubing 1/2-inch HPT to 3/6-inch NPT tuesting	Autoclave Engineers Restak	M615-081 21512	8.50 9.00	7.3 33.7	\$2.05 303.30 9.30
1/4-inch HP tube (per foot) 1/6-inch SS tubing 1/2-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male convector	Autociove Engineers Restek Suragelick	M615-081 21512 8-800-1-8	8.50 9.00 1.88 0.75 2.40	7.3 33.7 5	\$2.05 303.30
1/4-inch HP tube (per foot) 1/6-inch HP tube (per foot) 1/6-inch HPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male connector cabinet style work bench with leminated herdwood top 4/6-set/1-1-1-1-1-1-1-1-1-1-1	Autociave Engineers Restak Buragalok Lyon Matai Products	M615-061 21512 8-800-1-8 2844 (90/28/34 inches)	8.50 9.00 1.68 0.73 2.40 327.63	7.3 33.7 5 1	\$2.65 303.30 9.30 0.73 2.40 327.63
1/4-inch HP tube (per foot) 1/6-inch SS taking 1/2-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male connector cabinet style work banch NPT male connector 48x46x1/6-inch siloy 5/552 atuminum sheet 1 5/6x1 5/6-inchtx172-gauge metal framing channel (per foot)	Autociove Engineers Restek Suragelick	M615-081 21512 8-800-1-8 2844 (60:28x54 inches) 84865K76	8.50 9.00 1.66 0.73 2.40 327.63 88.00	7.3 33.7 5 1 1	\$2.65 303.30 9.30 0.73 2.40 327.63 \$6.00
1/4-inch HP tube (per foot) 1/6-inch SS tubing 1/2-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male connector cabinet style work banch with isministed hardwood top 48x46x1/6-inch alloy 5052 aluminum sheet 1 5/6x1 56-inchx1/2-gauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorew	Autoclave Engineers Restal: Buragelok Lyon Metal Products McMester-Cart	M615-061 21512 8-800-1-8 2844 (90/28/34 inches)	8.50 9.00 1.66 0.73 2.40 327.63 88.00 1.34	7.3 33.7 5 1 1 1 1 48	\$2,65 303,30 9,30 0,73 2,40 327,63 88,00 61,41
1/4-inch HP tube (per foot) 1/6-inch SS taking 1/2-inch NPT to 3/6-inch NPT bushing 1/2-inch NPT to 3/6-inch NPT male connector cabinat style work banch with laminated hardwood top 48x467/6-inch alloy 5052 atuminum sheet 1 5/6x1 5/6-inchx1 2-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorrer 1/4-inch lag sorrer	Autocleve Engineers Restek  Buragelick Lyon Metal Products McMester-Carr  B-Line	M615-081 21512 8-800-1-8 2844 (60:28x54 inches) 84865K76	8.50 9.00 1.86 0.75 2.40 327.63 86.00 1.34	7.3 33.7 5 1 1 1 1 48 7	\$2.65 303.30 9.30 0.73 2.40 327.63 88.00 61.41 2.10
1/4-inch HP tube (per foot) 1/6-inch HP tube (per foot) 1/6-inch SS tubing 1/6-inch SS tubing 1/6-inch tube to 3/6-inch NPT turehing 1/6-inch tube to 3/6-inch NPT male connector cabinat style work bench with leminated hardwood top 48x46178-inch step 5/652 aluminum sheet 1 5/6x1 5/6-inchtr12-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sourer 1/4-inch feet wisher Neo-hole comer engle	Autoclove Engineers Restak Buragelick Lyon Metal Products McMeater-Cart B-Line	M615-061 21512 8-600-1-8 2244 (60x28x34 inches) 44665K76 822	8.50 9.00 1.66 0.73 2.40 327.63 88.00 1.34	7.3 33.7 5 1 1 1 1 48	62.65 303.30 9.30 0.73 2.40 327.63 86.00 61.41 2.10 0.16
1/4-inch HP tube (per foot) 1/6-inch SS tating 1/2-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male connector cabinet style work banch NPT male connector cabinet style work banch with terminated hardwood top 48x46x1/6-inch alloy 5052 atuminum sheet 1 5/6x1 5/6-inchtx1/2-gauge metal framing channel (per foot) 1/4x1 1/4-inch lag serve 1/4-inch flat weather two-hole 'mo-twist' comer angle two-hole 'mo-twist' comer angle	Autoclove Engineers Restek Buragelok Lyon Metal Products McMester-Carr B-Line B-Line B-Line	M615-061 21312 8-800-1-8 2844 (80x28x34 inches) 84865K78 822 8101 8101	8.50 8.00 1.80 0.75 2.40 327.63 88.00 1.34 0.30 0.01 0.82 1.20	7.3 33.7 5 1 1 1 48 7 11 13 5	\$2.65 303.30 9.30 0.73 2.40 327.63 88.00 61.41 2.10
1/4-inch HP tube (per foot) 1/6-inch SS tubing 1/2-inch NPT to 3/6-inch NPT bushing 1/2-inch NPT to 3/6-inch NPT male convector cabinet style work bench with imministed herdwood top 48x4677.6-inch stop 5052 aluminum sheet 1 5/6x1 5/6-inch stop 5052 aluminum sheet 1 5/6x1 5/6-inch stop 5052 aluminum sheet 1/4-inch lag soraw	Autoclove Engineers Restak  Buragelok Lyon Metal Products McMester-Car  B-Line B-Line B-Line B-Line	M615-081 21512 8-800-1-8 2844 (80:28:234 inches) 88865K7s 822 8101 8201	8.50 9.00 1.86 6.73 2.40 327.83 86.00 1.34 0.30 0.01 0.92 1.20 0.34	7.3 33.7 5 1 1 1 1 48 7 11 13 5 5	62.65 503.30 6.50 6.73 2.40 327.63 86.00 61.41 2.15 0.16 11.86 6.00 2.76
1/4-inch HP tube (per foot) 1/6-inch SS taking 1/2-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male connector cabinat style work banch NPT male connector cabinat style work banch NPT male connector 48x46x1/6-inch alloy 5052 aluminum sheet 1 5/6x1 5/6-inchx1/2-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorrer 1/4-inch flat washer two-hole comer engle two-hole owner engle two-hole she-twist* comer angle square washer two-hole speedted sheff angle four hole comer plate	Autoclove Engineers Restat Buragelick Lyon Metal Products Michigater-Cart B-Line B-Line B-Line B-Line B-Line	M615-061 21312 8-600-1-8 2944 (60x28x34 inches) 44065K76 822 8101 8231 8250 8102	6.50 6.00 1.86 6.75 2.40 327.63 86.00 1.34 0.30 0.01 1.20 0.52 1.20 0.54	7.3 33.7 5 1 1 1 1 48 7 11 13 5 5	62.05 303.30 6.30 0.75 2.40 327.63 86.00 61.41 2.10 0.16 11.86 6.00 2.70 2.20
1/4-inch HP tube (per foot) 1/6-inch SS tubing 1/2-inch NPT to 3/6-inch NPT bushing 1/2-inch NPT to 3/6-inch NPT male convector cabinet style work bench with imministed herdwood top 48x4677.6-inch stop 3632 aluminum sheet 1.5-bict 5.6-inch	Autoclove Engineers Restak  Buragelok Lyon Metal Products McMester-Car  B-Line B-Line B-Line B-Line	M615-081 21512 8-800-1-8 2844 (80:28:234 inches) 88865K7s 822 8101 8201	6.50 9.00 1.00 0.73 2.40 327.63 86.00 1.34 0.30 0.01 0.02 1.20 0.52 1.20 0.53	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 303.30 9.30 0.73 2.40 327.65 86.00 61.41 2.10 0.16 6.00 2.76 2.86 11.86
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch HP to 3/6-inch NPT bushing 3/6-inch table to 3/6-inch NPT male connector cabinet style work bench with leminated herdwood top 4/6-inch table y 5/6-2 atuminum sheet 1 5/6-inch 1/2-y-gauge metal framing chennel (per foot) 1/4-inch lag sorw 1/4-2-2-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-	Autoclove Engineers Restat Buragelick Lyon Metal Products Michigater-Cart B-Line B-Line B-Line B-Line B-Line B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8200 8143	6.50 9.00 1.86 0.75 2.40 80.00 1.34 0.30 0.01 0.52 1.20 0.34 2.86 0.36	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.85 13.40 7.84
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1/4-inch HP tube (per foot) 1/6-inch SS taking 1/6-inch SS taking 3/6-inch tube to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male convector cabinet style work banch NPT male convector cabinet style work banch NPT male convector 6-8x46x1/6-inch alloy 5052 atuminum sheet 1 5/8x1 5/6-inchtr1 2-gauge metal framing channel (per foot) 1/4x1 1/4-inch lag serve 1/4-inch Rat weather two-hole comer angle two-hole comer angle two-hole short-wrist* comer angle square weather two-hole short-wrist* comer angle square weather two-hole short-wrist* comer angle 1/4-10-10-inch last head cap screw 1/4-10-11-11-11-11-11-11-11-11-11-11-11-11-	Autoclove Engineers Restek  Buragelok Lyen Metal Products  McMester-Carr  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line	M615-061 21312 8-800-1-8 2644 (80/26/24 inches) 84665K78 822 8101 8231 8200 8125 8143 Th/224	6.50 9.00 1.88 6.75 2.40 327.63 86.00 1.34 0.30 0.01 0.52 1.20 0.54 2.85 3.55 0.96	7.3 33.7 5 1 1 1 1 1 48 7 11 13 5 5 1 14 48 7	62.05 303.30 9.30 9.75 2.40 327.65 86.00 61.41 2.10 0.16 11.86 6.00 2.76 2.25 13.40 7.44 12.21 13
1/A-Inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch HP table-inch NPT bushing 3/6-inch table to 3/6-inch NPT male connector cabinet style work bench with leminated herdwood top 4/640547/6-inch alloy 5052 attentium sheet 1 5/641 5/6-inchot12-gaupe metal framing chennel (per foot) 1/441 1/4-inch lag sorw 1/4-inch fact washer hro-hole borner engle hro-hole "ho-twist" corner angle square washer hro-hole corner plate 1/4-2053/4-inch host heed cap screw 1/2-13 chennel nut 1/4-2053/4-inch host heed cap screw 1/2-13 chennel nut 1/4-1051/4-inch host heed cap screw 1/4-inch pipe clamp 1/4-inch pipe clamp	Autoclave Engineers Restat  Buragetot Lyon Metal Products McMester-Cart  B-Line	M615-061 21512 8-600-1-8 2644 (60x26x54 inches) 84665X76 822 8101 8231 8230 8125 8143 Th024 N224 N224 N224 82211 82211 8220 8125 8143	6.50 5.00 1.68 6.73 2.40 327.65 86.00 1.34 0.30 0.01 0.52 1.20 0.54 2.85 0.90 0.04 0.71	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 303.30 6.30 0.75 2.40 327.63 86.00 61.41 2.10 0.16 11.86 6.00 2.70 2.86 13.40 7.84
1/4-inch HP tube (per foot) 1/6-inch HP tube (per foot) 1/6-inch NPT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male convector cabinat style work bench with leminated hardwood top 48x46x1/6-inch alloy 5/652 aluminum sheet 1 5/6x1 5/6-inchx1/2-pauge metal framing chemiel (per foot) 1/4x1 1/4-inch lag sorrer 1/4-inch fiet wisher two-hole owner engle two-hole "hot-wrist" comer angle square wisher two-hole "hot-wrist" comer angle 1/4-12 chemiel nut 1/4-12 chemiel nut 1/4-20/4-inch hex head cap sorrer 1/2-13 chemiel nut 1/2-14-inch hex head cap sorrer 1/2-15 chemiel nut 1/2-16-inch pipe clamp 1 1/4-inch pipe clamp	Autoclove Engineers Restek  Buragelok Lyen Metal Products  McMester-Carr  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line  B-Line	M615-061 21312 8-800-1-8 2644 (80/26/24 inches) 84665K78 822 8101 8231 8200 8125 8143 Th/224	6.50 6.00 1.86 6.75 2.40 327.63 86.00 1.34 0.30 0.01 1.20 0.52 1.20 0.54 2.85 3.95 0.90 0.04 0.71 0.25	7.3 53.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 303.30 6.30 6.75 2.40 327.63 386.00 61.41 2.10 11.86 6.00 2.70 2.85 13.40 7.84 19.17 11.50 6.00 1.50
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch HP to 3/6-inch NPT bashing 3/6-inch table to 3/6-inch NPT male connector cabinet style work bench with leminated herdwood top 4/6-inch table to 5/6-inch NPT male connector cabinet style work bench with leminated herdwood top 4/6-inch table to 5/6-inch NPT male of the mining chennel (per foot) 1/6-inch 5/6-inchot12-gaupe metal framing chennel (per foot) 1/4-inch fact washer 1/4-inch fact washer 1/4-inch fact washer 1/6-inch inch her herd cap screw 1/6-inch specially 1/6-inch pipe clamp 1/6-inch pipe clamp 1/6-inch pipe clamp 1/6-inch raund head slotted screw 3/6-16 chennel mut 1/6-2001/2-inch raund head slotted screw 3/6-16 chennel mut 1/6-16-inch raund head slotted screw	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cert  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 9.00 1.86 0.75 2.40 0.90 1.33 0.30 0.01 0.52 1.20 0.34 2.86 0.94 2.86 0.94 0.94 0.94 0.94 0.94 0.94 0.95 0.96	7.3 \$3.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.95 1.22 1.24 1.25 1.25 1.25 1.25 1.26 1.27 1.26 1.27 1.26 1.27 1.26 1.27 1.26 1.27 1.26 1
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT basehing 3/6-inch table to 3/6-inch NPT male convector cabinat style work bench with leminated hardwood top 4/6-inch table 5/6-inch NPT male convector cabinat style work bench with leminated hardwood top 4/6-inch S6-inchtol 2-pauge metal framing channel (per foot) 1/4-inch seal comer angle 1/4-20-24-inch hist head cap screw 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-inch pipe clamp 1 1/2-inch not need soldted screw 3/6-18 channel nut 3/6-18 channel nut	Autoclave Engineers Restat  Buragetot Lyon Metal Products McMester-Cart  B-Line	M615-061 21512 8-600-1-8 2644 (60x26x54 inches) 84665X76 822 8101 8231 8230 8125 8143 Th024 N224 N224 N224 82211 82211 8220 8125 8143	6.50 9.00 1.86 0.75 2.40 0.327,45 86.00 1.34 0.30 0.91 0.52 1.20 0.54 2.95 0.94 0.71 0.94 0.71 0.90 0.91	7.3 33.7 5 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 3 5 7 1 1 1 1 1 1 3 5 5 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 6.30 6.75 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.85 13.40 1.96
1/4-inch HP tube (per foot) 1/6-inch SS taking 1/6-inch NPT to 3/6-inch NPT bushing 3/6-inch Nbs to 3/6-inch NPT male connector cabinat style work banch NPT male connector cabinat style work banch NPT male connector 68x66x1/6-inch alloy 5052 aluminum sheet 1 5/6x1 56-inchti12-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorrer 1/4-inch 8at washer two-hole comer single two-hole owner single two-hole inc-twist* comer angle 90;aare washer three-hole presented shelf angle four hole comer plate 1/4-20 channel nut 1/4-20x3/4-inch hist head cap sorrer 1/4-13x1 1/4-inch hist head cap sorrer 1/4-13x1 1/4-inch hist head cap sorrer 1/4-13x1 1/4-inch pipe clamp 1/4-20x1/2-inch raund head slotted sorrer 3/6-16 channel nut 1/6-16x1-inch hist head cap sorrer 3/6-16x1-inch nut head cap sorrer 3/6-16x1-inch nut head cap sorrer 3-3x5/6-inch ovel head Cap sorrer	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cert  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 9.00 1.88 6.75 2.40 327.83 86.00 1.34 0.30 0.01 0.82 1.20 0.54 2.85 3.95 0.90 0.04 0.71 0.22 0.23 0.90 0.91 0.92 0.93 0.94 0.95 0.9	7.3 53.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 9.75 2.40 327.63 88.00 61.41 2.10 11.86 6.00 2.70 2.85 13.40 7.84 1.22 18.17 11.50 1.60 1
1/A-Inch HP table (per foot) 1/B-inch HP table (per foot) 1/B-inch SS tabing 3/B-inch SS tabing 3/B-inch tube to 3/B-inch NPT bushing 3/B-inch tube to 3/B-inch NPT male connector cabinet style work bench with leminated herdwood top 4/Ast 1/B-inch alloy 5052 attentium sheet 1 5/Bct 5/B-inchot12-gaupe metal framing chennel (per foot) 1/Ast 1/A-inch lag sorw 1/A-toch fact washer hro-hole corner engle hro-hole "ho-twist" corner engle separe wesher hro-hole puseated shelf engle four hole corner plate 1/A-20c3/4-inch hox heed cap sorw 1/2-13 chennel nut 1/4-20c3/4-inch hox heed cap sorw 1/2-13 chennel nut 1/4-20c3/4-inch hox heed cap sorw 1/2-14-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch hox heed cap sorw 3/B-16 chennel nut 3/B-16-inch result heed cap sorw 3/B-16 chennel nut 3/B-16-inch result heed Philips corner 10-24z1 1/4-inch sockut heed cap sorw	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cert  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 9.00 1.86 0.75 2.40 0.327,45 86.00 1.34 0.30 0.91 0.52 1.20 0.54 2.95 0.94 0.71 0.94 0.71 0.90 0.91	7.3 33.7 5 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 3 5 7 1 1 1 1 1 1 3 5 5 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.95 12.2 19.17 11.50 0.80 1.64 1.65
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT bashing 3/6-inch table to 3/6-inch NPT make convector cabinat style work bench with leminated hardwood top 4x34011/6-inch stell sy 5/6-3 aluminum sheet 1 5/6c1 5/6-inchot12-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorw 1/4-inch fiet wisher Neo-hole owner engle Neo-hole hon-twist* comer angle Square wisher Neo-hole sho-twist* comer angle tour hole comer plate 1/4-20 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-14-inch hisc head cap screw 1/2-15 channel nut 1/2-16-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch not need solded screw 3/6-16-1-inch hisc head cap screw 6-32d/6-inch read head sp screw 6-32d/6-inch read head sp screw M4x10mm socket head cap screw M4x10mm socket head cap screw	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cert  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 9.00 1.86 0.75 2.40 0.90 1.33 0.00 1.34 0.30 0.01 0.52 1.20 0.34 2.85 0.94 0.94 0.94 0.94 0.95 0.96	7.3 \$3.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.96 13.40 1.22 19.17 1.30 0.00 1.41 1.96
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT bashing 3/6-inch table to 3/6-inch NPT make convector cabinat style work bench with leminated hardwood top 4x34011/6-inch stell sy 5/6-3 aluminum sheet 1 5/6c1 5/6-inchot12-pauge metal framing channel (per foot) 1/4x1 1/4-inch lag sorw 1/4-inch fiet wisher Neo-hole owner engle Neo-hole hon-twist* comer angle Square wisher Neo-hole sho-twist* comer angle tour hole comer plate 1/4-20 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-14-inch hisc head cap screw 1/2-15 channel nut 1/2-16-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch not need solded screw 3/6-16-1-inch hisc head cap screw 6-32d/6-inch read head sp screw 6-32d/6-inch read head sp screw M4x10mm socket head cap screw M4x10mm socket head cap screw	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cerr  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 5.00 1.88 6.75 2.40 327.65 86.00 1.34 0.30 0.01 1.20 0.54 2.85 3.35 0.94 0.71 0.25 0.25 0.25 0.30 0.64 0.30	7.3 \$3.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.95 12.2 19.17 11.50 0.80 1.64 1.65
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch table to 3/6-inch NPT bashing 3/6-inch table to 3/6-inch NPT male convector cabinat style work bench with leminated hardwood top 48-s861/8-inch story 5/552 aluminum sheet 1 5/6c1 5/6-inchort 2-pauge metal framing channel (per foot) 1/4-11 3/4-inch lag sorw 1/4-inch fiet wisher Neo-hole owner engle Neo-hole sho-twist* comer angle Square wisher Neo-hole sho-twist* comer angle 14-20 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-13 channel nut 1/2-14-inch hist head cap screw 1/2-15 channel nut 1/2-1-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch pipe clamp 1 1/2-inch not head op screw 3/6-16/1-inch hist head cap screw 3/6-16/1-inch hist head cap screw 1/4-16/1-inch hist head cap screw 1/4-inch list washer	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cerr  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 9.00 1.86 0.75 2.40 0.30 0.30 0.91 0.52 1.20 0.54 2.95 0.94 0.71 0.94 0.71 0.95 0.96 0.91 0.92 0.92 0.93 0.94 0.95	7.3 33.7 5 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 0.16 11.86 6.00 2.70 2.96 13.40 1.22 18.17 1.30 0.00 1.41 1.96 6.00 2.70 2.96 13.40 0.00 1.41 1.22 18.17 1.30 0.00 1.41 1.41 1.41 1.50 1.41 1.50
1/4-inch HP tube (per foot) 1/6-inch SS taking 1/6-inch NBT to 3/6-inch NPT bushing 3/6-inch tube to 3/6-inch NPT male convector cabinat style work bench NPT male convector 1 5/6c1 5/6-inch 1/2 y 5/6-3 aluminum sheet 1 5/6c1 5/6-inch 1/2 y 5/6-3 aluminum sheet 1 1/4-inch flat washer 1/4-inch flat washer 1/4-inch flat washer 1/4-inch somer engle 1/4-10 channel nut 1/4-10c1/4-inch has head species 1/4-20 channel nut 1/2-13 channel nut 1/2-15/1 1/4-inch has head cap screw 1/2-13 channel nut 1/2-15/1 1/4-inch has head cap screw 1/2-13 channel nut 1/2-15/1 1/4-inch has head cap screw 1/2-13/6-inch nut head Phillips screw 1/2-13/6-inch nut head cap screw 1/2-13/6-inch nut head cap screw 1/2-16/1-inch size head cap screw 1/2-inch size washer 1/2-inch size washer	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cerr  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 8.00 1.88 6.75 2.49 327.63 86.00 1.34 0.30 0.91 0.52 1.20 0.54 2.85 3.55 3.55 0.94 0.71 0.71 0.72 0.82 0.94 0.75 0.94 0.94 0.94 0.95 0.94 0.95 0.9	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 6.30 6.30 6.75 2.40 61.41 2.10 6.06 6.06 6.07 2.75 2.95 13.40 1.22 19.17 1.44 1.44 1.44 1.40 1.41 1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.44 1.45 1.44 1.45 1.44 1.45
1.74-inch HP table (per foot) 1.76-inch HPT table-inch HPT bashing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT male connector cabinet style work bench with leministed herdwood top 4/6-style work bench with leministed herdwood top 4/6-style-inchest 2-gauge metal framing chennel (per foot) 1.76-style-inchest 2-gauge metal framing chennel (per foot) 1/6-style-inchest 2-gauge metal framing chennel (per foot) 1/6-style-inchest agenre 1/6-style-inchest senter 1/6-style-inchest senter 1/6-style-inchest senter 1/6-style-inch hist head cap serve 1/6-style-inch serve nut 1/6-style-inch serve n	Autoclove Engineers Restek  Beragelok Lyen Metal Products  McMester-Cerr  B-Line	M615-061 21312 8-800-1-8 2844 (60/28/54 inches) 84865K76 822 8101 8231 8200 8143 Th/224 M225 844C8 1/2" x 1 1/4" 8221	6.50 8.00 1.86 6.75 2.40 327.63 86.00 1.34 0.30 1.20 0.01 1.20 0.54 2.85 3.95 0.90 0.04 0.71 0.25 0.20 0.32 0.30 0.04 0.04 0.04 0.04 0.05 0.0	7.3 \$3.7 \$ 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 61.41 2.10 0.16 11.86 6.00 2.70 2.95 12.2 1.22 1.23 1.24 1.25 1.34 1.25 1.34 1.25 1.35 1.36 1
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT bashing 3/6-inch table to 3/6-inch NPT male convector cabinat style work bench with leminated herdwood top 4/6-inch table y 5/5-2 atuminum sheet 1 5/6-inch s6-inch 1/2-yeape metal framing channel (per foot) 1/4-11 3/4-inch lag sorw 1/4-inch 6-inch server two-hole comer engle two-hole comer engle two-hole comer engle two-hole comer plate 1/4-inch lag sorw 1/4-12 channel nut 1/4-20 c/4-inch hox head cap sorw 1/2-13 channel nut 1/4-10-11-inch hox head cap sorw 1/2-13 channel nut 1/4-inch pipe clamp 1/4-20-12-inch mand head slotted sorw 1/4-10-13-inch hox head cap sorw 1/4-10-14-inch hox head cap sorw 1/4-16-inch pipe clamp 1/4-20-13-inch number plate 1/4-16-inch hox head cap sorw 1/4-16-inch pipe clamp 1/4-inch sochat head cap sorw 1/4-16-inch hox head cap sorw 1/4-16-inch pipe clamp 1/4-inch sochat head cap sorw 1/4-16-inch sochat head cap sorw 1/4-inch sochat head cap sorw	Autoclave Engineers Restak  Beragelick Lyen Metal Products Michiester-Cart B-Line	M615-061 21312  8-600-1-8 2944 (60x26x54 inches) 44665K76 822  8101 8231 8230 8125 8443 Th224  H225 H428 1/2" x 1 1/A" 82212  H226	6.50 9.00 1.86 0.75 2.40 88.00 1.34 0.30 0.91 0.52 1.20 0.54 2.95 3.55 0.94 0.71 0.25 0.80 0.61 0.71 0.72 0.80 0.73 0.80 0.74 0.80 0.91 0.92 0.94 0.94 0.94 0.95 0.96 0.96 0.96 0.96 0.96 0.97 0.96 0.97	7.3 33.7 5 5 1 1 1 1 1 1 1 1 1 1 1 1 3 5 5 1 1 1 1	62.05 503.30 9.30 0.73 2.40 0.16 11.86 6.00 2.70 2.95 13.40 0.96 1
1/4-inch HP table (per foot) 1/6-inch SS taking 1/6-inch NBT to 3/6-inch NPT bushing 3/6-inch table to 3/6-inch NPT male convector cabinat style work bench NPT male convector 1 5/6c1 5/6-inch cab style 1 5/6c1 5/6-inch cab style 1 1/4-inch Set washer 1/4-inch Set inches to set cap serve 1/4-12 channel nut 1/2-13 channel nut 1/2-15 channel nut 1/2-16 shownel nut 1/2-16 channel nut 1/2-16 machine serve nut 1/2-16 m	Autocieve Engineers Restat  Beragetot Lyon Metal Products McMeeter-Cert  B-Line	M615-061 21512 8-600-1-8 2644 (60x26x54 inches) 84665X76 822 8101 8230 8125 8143 Th/224 M226 M226 M226	6.50 8.00 1.86 6.75 2.40 327.63 86.00 1.34 0.30 1.20 0.01 1.20 0.54 2.85 3.95 0.90 0.04 0.71 0.25 0.20 0.32 0.30 0.04 0.04 0.04 0.04 0.05 0.0	7.3 \$3.7 \$ 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 6.30 6.75 2.40 61.41 2.10 0.16 11.86 6.00 2.75 2.95 13.40 1.22 19.17 1.22 19.17 1.44 1.44 1.49 1.40
1.1.4-inch HP table (per foot) 1.76-inch HPT table-inch HPT bashing 3.6-inch table to 3.6-inch NPT male connector cabinet style work bench with leministed herdwood top 4.6-inch table to 3.6-inch NPT male connector cabinet style work bench with leministed herdwood top 4.6-inch table to 3.6-inch NPT male connect top 1.5-fact 5.6-inch 1.2-gauge metal framing chennel (per foot) 1.7-inch 1.6-inch 1.6-	Autoclave Engineers Restak  Beragelick Lyen Metal Products Michiester-Cart B-Line	M615-061 21312  8-600-1-8 2944 (60x26x54 inches) 44665K76 822  8101 8231 8230 8125 8443 Th224  H225 H428 1/2" x 1 1/A" 82212  H226	6.50 8.00 1.88 6.75 2.49 86.00 1.34 0.30 0.01 0.54 2.85 3.85 0.94 0.04 0.71 0.25 0.82 0.82 0.84 0.75 0.84 0.85 0.85 0.86 0.86 0.87 0.87 0.87 0.88	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 503.30 9.30 0.73 2.40 0.16 11.86 6.00 2.70 2.95 13.40 0.96 1
1/4-inch HP table (per foot) 1/6-inch HP table (per foot) 1/6-inch SS tabing 3/6-inch SS tabing 3/6-inch table to 3/6-inch NPT baseling 3/6-inch table to 3/6-inch NPT male convector cabinet style work bench with leminated herdwood top 4/6-inch table y 5/6-3 atuminum sheet 1 5/6-1 5/6-inchot12-gauge metal framing chennel (per foot) 1/4-11 3/4-inch lag sorw 1/4-inch feet wisher two-hole comer engle two-hole comer engle two-hole comer pate 1/4-inch lag sorw 1/4-inch lag sorw 1/4-13-13-14-inch hole hole of angle four hole comer pate 1/4-20-3/4-inch hole hole of angle 1/4-20-3/4-inch hole hole of angle 1/4-20-3-1-3/4-inch hole hole of angle 1/4-20-3-1-3-1-3-1-3-1-3-1-3-1-3-1-3-1-3-1-3-	Autoclave Engineers Restak  Beragelick Lyen Metal Products Michiester-Cart B-Line	M615-061 21312  8-600-1-8 2944 (60x26x54 inches) 44665K76 822  8101 8231 8230 8125 8443 Th224  H225 H428 1/2" x 1 1/A" 82212  H226	6.50 8.00 1.86 0.75 2.40 1.32 1.32 1.32 1.32 1.32 1.33 1.30 0.01 0.52 1.20	7.3 33.7 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	\$2.05 \$03.30 9.30 0.75 2.40 327.63 88.00 61.41 2.10 11.86 6.00 2.70 2.35 13.40 7.44 1.22 19.17 11.50 1.60 1
1.1.4-inch HP table (per foot) 1.76-inch HPT table-inch HPT bashing 3.6-inch table to 3.6-inch NPT male connector cabinet style work bench with leministed herdwood top 4.6-inch table to 3.6-inch NPT male connector cabinet style work bench with leministed herdwood top 4.6-inch table to 3.6-inch NPT male connect top 1.5-fact 5.6-inch 1.2-gauge metal framing chennel (per foot) 1.7-inch 1.6-inch 1.6-	Autoclave Engineers Restak  Beragelick Lyen Metal Products Michiester-Cart B-Line	M615-061 21312  8-600-1-8 2944 (60x26x54 inches) 44665K76 822  8101 8231 8230 8125 8443 Th224  H225 H428 1/2" x 1 1/A" 82212  H226	6.50 8.00 1.86 6.75 2.40 327.63 86.00 1.34 0.30 0.91 1.20 1.20 0.92 1.20 0.94 2.95 3.9	7.3 \$3.7 \$5.7 \$1 1 1 1 1 1 1 1 1 1 1 1 1 1	62.05 303.30 0.75 2.40 327.63 380.00 61.41 2.10 11.86 6.00 12.70 2.70 2.85 13.40 7.44 1.86 1
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Table 2. Sources for components used in construction of the pressure test bench.

COMPANY [PARENT COMPANY]	LOCATION	TELEPHONE	INTERNET ADDRESS
ARO [Ingersoll-Rand]	Bryen, OH	(419) 636-4242	http://www.aro.ingersoli-rand.com/
Ashcroft [Dresser Instrument Division]	Stratford, CT	(203) 378-5281	http://www.dresser.com/instruments/
Autoclave Engineers (Snap-tite)	Erie, PA	(814)-838-5700	http://www.anap-tite.com/ae/
B-Line [Sigma-Aldrich]	Highland, IL	(618) 654-2184	http://www.bline.com/
BOC Gases	Murray Hill, NJ	(906) 464 8100	http://www.bocgases.com/
BuTech Pressure Systems	Erie, PA	(814) 833-4904	http://www.ncinter.net/~butech/
Cejon [Swagelok]	Macedonia, OH	(440) 349-5934	http://www.swapelok.com/
Circle Seal Controls	Corona, CA	(909) 270-6200	http://www.circle-seal.com/
Fisher Scientific	Pittsburgh, PA	(412) 490-8300	http://www.fishersci.com/
General Cable	Highland Heights, KY	(606) 572-8000	http://www.generalcable.com/
Haskel International	Burbank, CA	(818) 843-4000	http://www.haskel.com/
High Pressure Equipment	Ene, PA	(814) 838-2028	http://www.highpressure.com/
Lyon Metal Products	Aurora, IL	(630) 892-8941	http://www.lyonmetai.com/
Matheson Tri-Gas	Parsippany, NJ	(973) 257-1100	http://www.mathesonges.com/
McMaster-Carr	Elmhurst, IL	(630) 833-0300	http://www.mcmaster.com/
Nupro (Swagelok)	Willoughby, OH	(440) 349-5934	http://www.swagelok.com/
Oseco	Broken Arrow, OK	(915) 258-5626	India was sandani santa
Pomone	Pomone, CA	(909) 489-2900	http://www.pomonselectronics.com/
Restek	Belleforite, PA	(814) 353-1300	http://www.restekcorp.com/
Swagelok	Solon, OH	(440) 349-5934	http://www.swagelok.com/
Wallace & Tiernan	Belleville, NJ	(973) 759-8000	http://www.wandt.com/
Weathernead [Dans]	Toledo, OH	(419) 891-2800	
Whitey [Swagelok]		(440) 349-5934	http://www.dene.com/weatherhead/ http://www.swagelok.com/

The versatility of channel strut metal framing was used to an advantage for constructing the framework of the test bench. Components were mounted on the open framework built with 1-5/8 inch square galvanized steel channel strut (B22; B-Line). This frame was attached to a 60-inch by 28-inch wood-top workbench. Dimensions for the frame were determined after taking into consideration the space needed for the various components. Aluminum panels, 1/8-inch thick and sheared to size, were attached to the frame to accommodate panel-mount gauges and valves. A 14-inch by 12-inch aluminum panel was also sheared and installed as a shelf below the low pressure test section.

Dimensional layout of the frame and panels was performed using a Computer Aided Design (CAD) software program, "TurboCAD for Windows" version 1.02 (IMSI, San Rafael, CA). Outlines of the various components were drawn at 4:1 or 6:1 scales and arranged to create a functional and aesthetically pleasing layout. These drawings are shown in Figures 4, 5, 6, and 7.

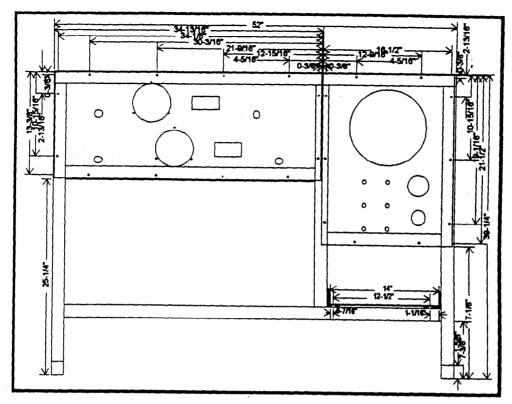


Figure 4. Frame layout.

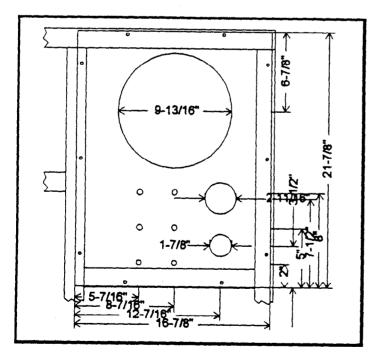


Figure 5. Low pressure panel layout.

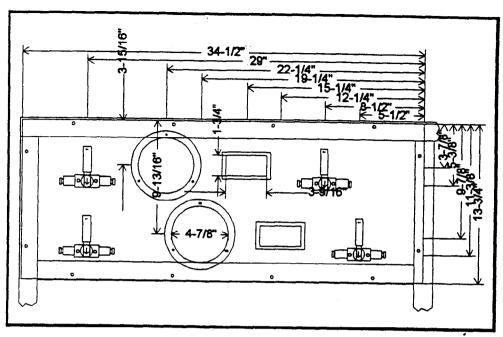


Figure 6. High pressure panel layout.

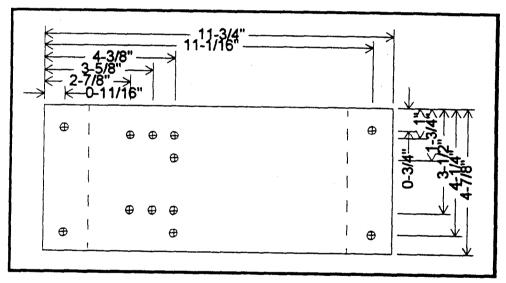


Figure 7. Electrical signals connection panel layout.

Dimensions taken directly from the CAD drawings were used to fabricate the channel strut frame and aluminum panels. The framework outside dimensions are 52 inches wide, 12 inches deep, and 39-1/4 inches high. Corner angle channel strut components (B231, B101; B-Line) were used to fasten the lengths of channel strut together to make the frame.

The low pressure test section incorporates a surplus precision 100 psi, 8-1/2 inch diameter, double-revolution dial pressure gauge [G-A]. A relief valve [RV-A], set at 100 psi, protects this gauge from over pressurization. One-quarter inch bulkhead unions (B-400-61; Swagelok) provide convenient test port connection points. One-quarter inch plastic tubing (PT-240-04; Weatherhead) was used to connect components behind this panel.

Four existing ball valves [L1, L2, H1, H2] were mounted on the panel of the high pressure test section, along with analog and digital pressure gauges. Existing 3-way/2stem manifold valves [L3-L4, H3-H4, H5-H6, H7-H8] were used to advantage, since they reduced the number of tube connections. These valves were mounted on four-hole corner plates (B143; B-Line) modified with two 10-24 tapped holes. This provided a secure mounting for the valves through a simple connection to the frame using 1/2-13 hex head cap screws (HHCS 1/2" x 1 1/4"; B-Line) and channel nuts (N225; B-Line). Relief valves [RV-1, RV-2, RV-3] to protect the gauges [G-L, G-H], the transmitters [PT-L, PT-H]. and the pressure generator [P2] were mounted to the frame with channel strut pipe clamps (B2211, B2212; B-Line). A 1-1/2 inch diameter hole was cut into a three-hole gussetted shelf angle (B125; B-Line) to accommodate mounting of the tank regulator [REG-G]. One-quarter inch O.D., 0.083 inch I.D. high pressure tube, rated for 60,000 psi (MS15-081; Autoclave Engineers), and 1/4 inch O.D., 0.109 inch I.D. medium pressure tube. rated for 20,000 psi (MS15-092; Autoclave Engineers), were used to interconnect components in this section. The one exception was from the cylinder tank check valve [CV] to the input side of the tank regulator [REG-G], where 1/8 inch O.D., 0.085 inch I.D. stainless steel tubing (21512; Restek) was used.

#### Performance

External pressure connections to the low pressure test section are made through 1/4 inch compression fittings (Swagelok -400 connection type). Adapters have been made to accommodate connections to components with other type connection ports.

External pressure connections to the high pressure test section are made through 1/4 inch standard high pressure cone and thread connections (Autoclave Engineers F250C connection type). The one exception is at the regulated tank output valve [L0],

where the output connection is made with a 1/8 inch gland and compression sleeve (Autoclave Engineers W125 connection type). Connection adapters have also been made for this test section.

The pressure test bench permits a multitude of test configurations. Graphic layouts, shown for the high pressure test panel in Figure 8, were drawn on both panels with permanent markers to indicate device interconnections for straightforward use of the test bench.

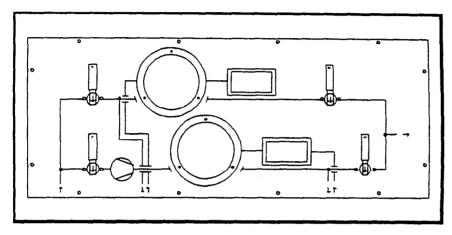


Figure 8. High pressure test panel graphic layout.

Though operation of the test bench is intuitive, step-by-step test procedures have been developed for various components. Figure 9 shows one of these procedures.

	w and high pressure test sections to test an air-driven has booster pump:
	stor REG-A and tank regulator REG-G are adjusted fully counterclockwise.
	of pump-under-teet to REGULATED TANK OUTPUT port.
Connect gas outpu	t of pump-under-test to 20,000 psi GAUGE EXTERNAL INPUT port.
Connect air drive is	put of pump-under-test to REGULATED AIR OUTPUT port.
Close valves A1, L	2, L4, H1, H5, H6, H7.
Open valves A0, L	, L1, L3, H2, H3, H4.
Adjust tank regulat	or REG-G for desired gas input pressure for pump-under-lest as observed on gauge G-L and indicator PI-L.
Adjust air regulator	REG-A to obtain desired gas output pressure for pump-under-test as observed on gauge G-H and indicator PI-H.
Open valve H6 wh	n it is dealred to vent gas output pressure for pump-under-test.
Before disconnecti	ng pump-under-test, adjust air regulator REG-A and tank regulator REG-G fully counterclockwise and open valve H

Figure 9. Sample test procedure.

One consideration needs to be noted when using the gas booster pump [P1] and the hand pump pressure generator [P2]. Adjustments made with the pressure generator [P2] to lower the test pressure below the set pressure of the booster pump [P1] will be

canceled out by the compensating action of the booster pump [P1] returning to its set pressure. Therefore, the pressure setting of the booster pump [P1] needs to be kept lower than the pressure that the pressure generator [P2] will be adjusted to. (Increasing test pressures generated by the pressure generator [P2] are not compensated by the booster pump [P1] due to operation of the booster pump's [P1] internal check valve.)

As with any system that develops high pressures, intended actions need to be thought through with safety in mind. Venting of test gases away from personnel is a must. All vent valves on this test bench discharge to the back of the bench, away from personnel. Tubing used to connect the test bench to the device-under-test must be adequately rated for the pressure that will be applied. Connections should not be broken until all pressure has been relieved from the device-under-test. Testing should always start with all pressure regulator knobs turned fully counterclockwise (zero pressure). The appropriate responsive action to an unexpected failure of a device-under-test should be determined before a test procedure is initiated.

## **Data Acquisition**

Provisions were made through the electrical signals connection panel to measure and record the 4 to 20 mA signals from the pressure transmitters [PT-L, PT-H]. A schematic showing the wiring and operation of one of the two identical channels of the electrical signals connection panel is shown in Figure 10.

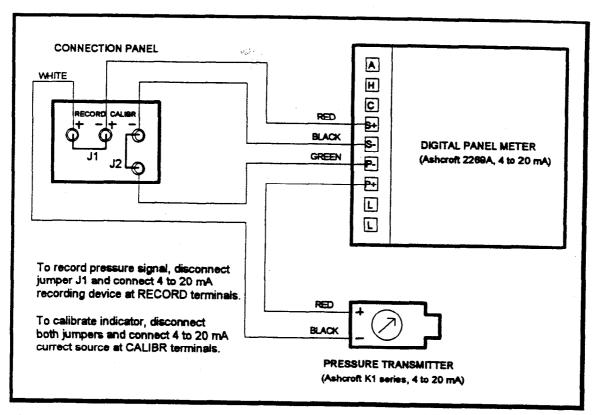


Figure 10. Schematic for one-half of the electrical signals connection panel.

Data was recorded during a test of a used relief valve that provides an example of this test bench feature. This data was collected from the 20,000 psi pressure transmitter [PT-H] using National Instruments (Austin, TX) SCXI hardware and LabVIEW version 5.0.1 software. Figure 11 shows the pressure relieving performance of the used relief valve set at approximately 9000 psi and checked in two different ways.

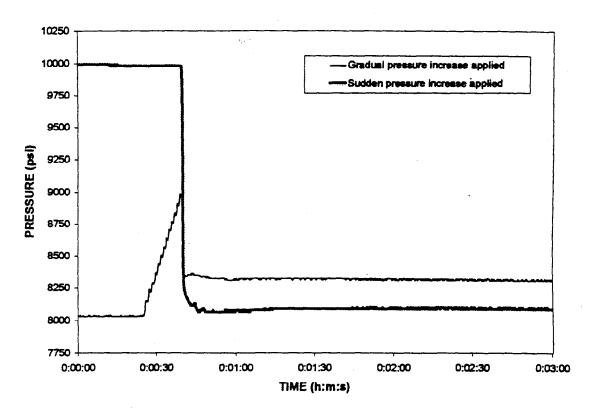


Figure 11. Performance of relief valve-under-test.

The first method applied a gradual increasing pressure to the relief valve: Booster pump [P1] was used to pressurize the relief valve, connected at the TEST PORT of test output valve [H7], to an initial 8000 psi. Then pressure generator [P2] was rotated clockwise (approximately 14 half-turns) to actuate the relief valve. The second method applied a sudden over-pressurization of 10,000 psi to the relief valve: Booster pump [P1] was used to pressurize the relief valve to 8000 psi. Next, test output valve [H7] was closed, and the test bench was pressurized to 10,000 psi. After turning drive regulator [REG-D] fully counterclockwise, test output valve [H7] was quickly opened, permitting actuation of the relief valve.

The electrical signal connections panel also provides a convenient manner for external calibration of the digital panel meters (indicators) [PI-L, PI-H] with a current-sourcing 4 to 20 mA calibrator.

#### Conclusion

Components utilized in supercritical fluid research are often incorporated without initially testing their condition. Used components, as described previously, should be routinely tested to see if they are in a safe condition and meet operational specifications. The described pressure test bench was built by taking advantage of existing parts and incorporating components that are used in the NCAUR Critical Fluids Research Program. The pressure test bench is designed specifically for evaluating components routinely used in supercritical fluid research.

In the future a mass flowmeter will be added to the test bench to provide flow calibration capability. Performance of the described test bench has met desired expectations and supplied the laboratory with a needed testing apparatus.

## Acknowledgments

Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

- (1) Friedrich, J. P. Wheels Make High-Pressure Research Roll. Annals of the New York Academy of Sciences 1970, 172, 155-174.
- (2) King, J. W. Analytical-Process Supercritical Fluid Extraction: A Synergistic Combination for Solving Analytical and Laboratory Scale Problems. *Trends in Anal. Chem.* 1995, 14, 474-481.

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